GENERAL ATOMIC

Division of General Dynamics Corporation

John Jay Hopkins Laboratory
for Pure and Applied Science

GPO PRICE $ _____

OTS PRICE(S) $ _____

Hard copy (HC) $2.00

Microfiche (MF) .50

GACD-4768
Copy No. 3

STUDIES OF THERMIONIC MATERIALS FOR SPACE POWER APPLICATIONS

NAS 3-4165

Informal Monthly Report for the Period
October 1, 1963 through October 31, 1963

Work done by:

Members of the Thermionic
Direct Conversion Group and
the Fission Product Study Group

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Project No. 373
Contract No. NAS 3-4165
National Aeronautics and Space Administration

The work carried out under Contract NAS 3-4165 in October, 1963, is summarized as follows:

1. Fabrication Development

1.1 UC-ZrC Fuels

Isostatic Pressing

Work reported on isostatic pressing development for the previous monthly period showed that the method was feasible for producing UC-ZrC compacts of more uniform and higher density than by ordinary cold pressing techniques. Work carried out during this period showed that in the case of the 30 UC - 70 ZrC composition a rather uniform pore distribution resulted when -325 mesh powder was used. Studies made by using ZrC powder also indicated that tapered ends were required on the cavity of the isostatic medium mold (Chemosol is presently being used) in order to consistently produce pressings which did not contain transverse cracks. Careful measurements of pressings made in molds with straight cylindrical cavities showed that the ends were a few thousandths of an inch larger in diameter than the center of the specimen. Apparently when the pressure was released after compaction the specimen was pulled apart axially and transverse cracks formed as the mold sprang back to its original length and shape with the larger ends of the compact held in the mold. Pressings made in the tapered cavity molds could be readily removed from the mold after pressing by having the mold split longitudinally on one side. Studies will be made on 30 UC - 70 ZrC in the tapered mold during the coming month.

Pore Control

Since narrow fractions of particle size (-100/+150, -150/+220, -220/+325 mesh; or -150/+100, -100/+65, -65/+45 microns) have resulted

in unsatisfactorily low densities in pressed and sintered compacts even in 90 UC - 10 ZrC compositions, some 90 UC - 10 ZrC powder of -75/+20 micron size has been prepared and pressed into a compact which is being sintered. It is believed that use of a larger particle size fraction will result in higher densities than previously obtained and yet produce a structure which has the desirable open pore structure. This is expected because the compacts pressed of the above mentioned narrower particle size fractions did have a rather uniform open type pore structure when examined metallographically; the specimens were unsatisfactory in that the density was too low.

Control of Carbon Content in Finished UC-ZrC Specimens

Previous work at General Atomic has shown that the carbon content of UC-ZrC can be reduced by heating specimens in the presence of flowing H_2 at 1800°C. In order to increase the carbon content in these types of specimens, it was thought that a possible method would be to pass a mixture of H_2 and a hydrocarbon vapor over a UC-ZrC specimen at 1800°C. This method was tried by heating two 80 UC - 20 ZrC specimens for 15 hours at 1700/1800°C in a gas mixture formed by passing H_2 at one atm. at a rate of 2 cu. ft./hr. through n-heptane maintained at 25°C. Metallographic examination of one specimen showed that a fine substructure was formed at the 1800°C end of the specimen; at the 1700°C end of the specimen a new phase was formed right at the surface and during cooling some of this "case" spalled off. Identification of this phase has not yet been accomplished. Chemical analysis indicated a decrease, rather than an increase, in the carbon content on both ends of the specimen, the decrease being larger at the 1800°C end. This probably

means that the H_2 content of the gas mixture was too high and a lower H_2 to hydrocarbon ratio will have to be tried. No oxidation was evident in the specimen, showing that the gases used were quite pure. Microprobe analysis has been requested on the specimen to identify the change in structure.

Gas-Metal Reaction Method for Producing Stoichiometric Carbides

A batch of 30 UC - 70 ZrC which had been prepared by hydriding and reaction with methane previously (but did not result in stoichiometric C content) was ground to -325 mesh and reacted with methane in the shaker furnace at 980°C for another 6 hours. A trap was used to remove hydrogen from the reaction tube. Chemical analysis of the resulting powder (which did not sinter during reaction) showed that the carbon content was 7.8 to 8.2%, while the stoichiometric carbon content for the 30-70 composition is 8.12%C. A specimen is being pressed from the material for evaluation. The above demonstrates that the gas-metal reaction method is amenable to producing essentially stoichiometric carbides even for high ZrC-containing UC-ZrC materials.

1.2 Vapor Deposited Tungsten

Assembly of the apparatus for the vapor deposition of tungsten was continued during this past month as requestioned items were received. The construction of the apparatus will be continued during next month. Preliminary experiments to check vacuum tightness and general operation conditions and the calibration of the flow meters will also be conducted.

A technical conference on tungsten vapor deposition was held on the 25th of October at the San Fernando Laboratory. Included in the conference were Dr. Bill Hoblman and Mr. Earl Atkins of the Lawrence Radiation

Laboratory, and Mr. Bob Holzl of San Fernando Laboratory. Also in attendance was Mr. Fred Glasky and Mr. John Keeler of the NASA's Western Operation Office, and General Atomic representatives.

2. Measurements of High Temperature Properties of Thermionic Materials.

2.1 Rate of Vaporization as a Function of Pore Structures of UC-ZrC

Measurement of the Langmuir vaporization rate of sample A_1-1 (hot-pressed, 96% dense) is being made. BET and pore size distribution studies will be carried out on this sample after the completion of the vaporization studies. This should set the lower limits of the BET area and the vacuum vaporization rate of 30 UC - 70 ZrC. Another sample A_2-1 which is a cold-pressed and sintered 30 UC - 70 ZrC of about 76% theoretical density has been prepared. Studies of this sample should set the upper limits of these properties for 30 UC - 70 ZrC. 30 UC - 70 ZrC sample of intermediate density will be studied afterwards.

Determination of Surface Roughness Factor of UC-ZrC Specimens

A BET low pressure adsorption apparatus has been built for measuring the surface roughness factor of UC-ZrC specimens, utilizing Kr adsorption at the boiling point of liquid nitrogen. To test the apparatus, measurements were made on a cold pressed and sintered stoichiometric 90 UC-10 ZrC specimen which had been annealed at 1900°C for 12 hours and had a density of 81% of the theoretical value. The specimen was 0.482 inch in diameter, 0.337 inch long, and weighed 10.594 grams. The plot of the volume (reduced to 0°C and 1 atm.) of Kr adsorbed by the specimen versus the relative pressure $\frac{p}{p_o}$ is shown in Fig. 1, where p is the equilibrium pressure of Kr in the vapor phase for a given amount of adsorption and p_o is the vapor pressure of Kr at the boiling point of liquid nitrogen (1.78 torr). The point A where the curve changes into the straight line portion corresponds to monolayer adsorption. In Fig. 1, A occurs at an adsorption of 0.12cc Kr

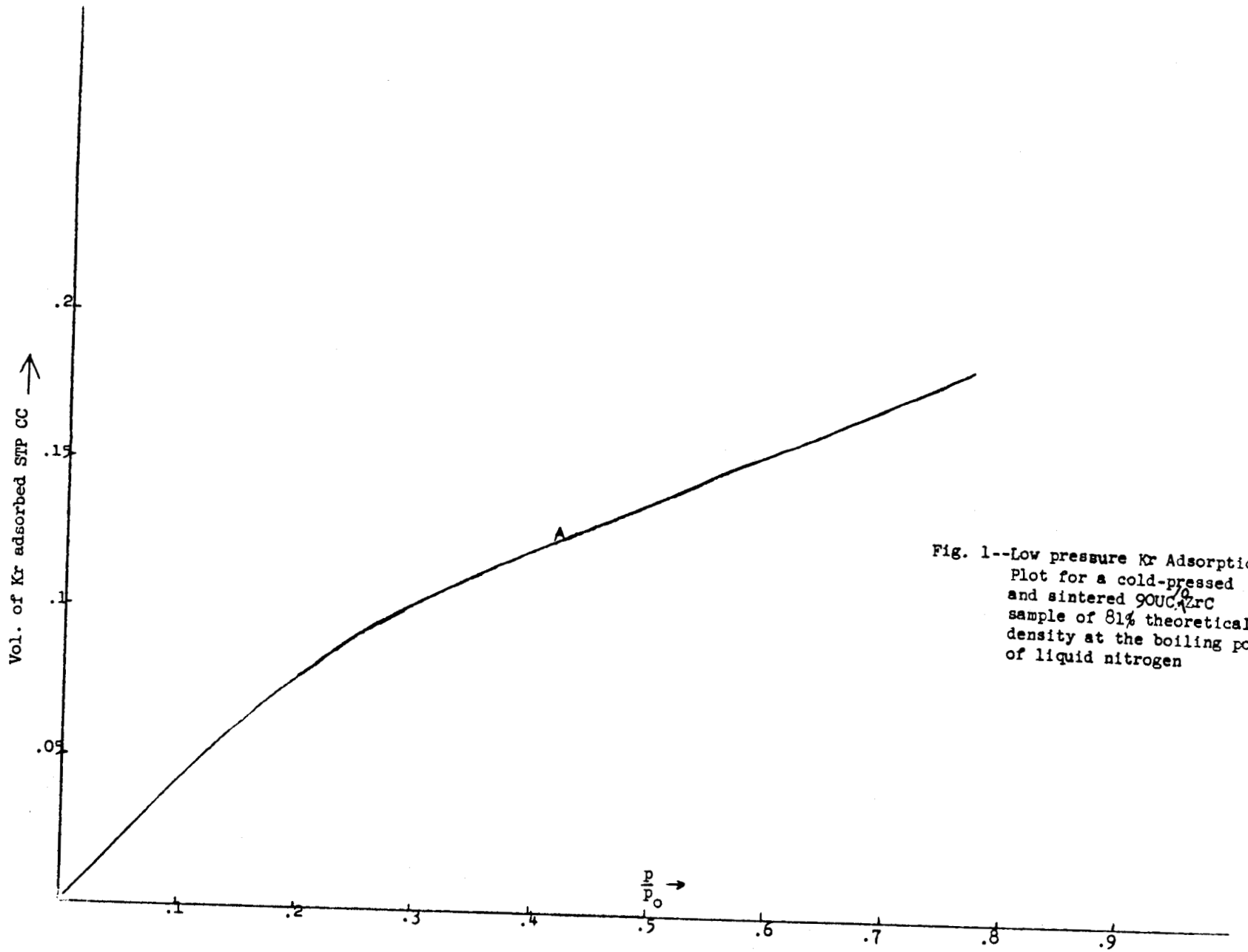

Fig. 1--Low pressure Kr Adsorption Plot for a cold-pressed and sintered 90UC-10ZrC sample of 81% theoretical density at the boiling point of liquid nitrogen

under standard conditions, (i.e., $0^{\circ}C$ and 1 atm.), or 3.26×10^{18} Kr atoms. Since 10^{15} Kr atoms occupy 1 cm^2, therefore the total surface area of the sample is 3260 cm^2 as compared to a geometric area of 5.63 cm^2. The surface roughness factor is thus 579. Currently measurements are being made on another cold-pressed and sintered 90 UC - 10 ZrC sample of 90% theoretical density. Once the apparatus is checked in, similar measurements will be carried out on other UC-ZrC samples fabricated under different conditions.

2.2 Fission Product Release from UC-ZrC.

Sample A_1-2 cut from the same carbide cylinder as sample A_1-1 (see Section 2.1) has been studied at $1800^{\circ}C$ by the post-irradiation annealing method. A_1-2 is a hot-pressed 30 UC-70 ZrC wafer (3/8 inch in diameter and 0.06 inch thick, 10% enrichment) of 96% theoretical density. It has been outgassed in vacuum at $1900^{\circ}C$ for a period of 22 hours and stored in helium prior to the irradiation.

A_1-2 was irradiated in an aluminum purge can which was carefully leak-checked prior to the irradiation. Thus, recoil release could be measured by purging the Xe^{133} released into the can before the high temperature annealing treatment. The sample was irradiated in TRIGA reactor to a total of 6×10^{13} fission, as determined from 1.60 mev γ-activity of La^{140} which is a daughter product of the primary fission product Ba^{140}. After the irradiation, the sample was stored for 5 days to get rid of the short half-life fission products. The La^{140} activity was counted and the recoil release of Xe^{133} was then determined by flushing the aluminum can with purified He and trapping the Xe^{133} in liquid nitrogen-cooled charcoal trap. After the determination of the recoil release, the sample was removed from the can and placed inside a

tungsten sleeve which was then loaded into the annealing furnace. The tungsten sleeve was used to avoid the contact between the carbide sample and the graphite heater of the furnace.

To avoid thermal shock, the sample was brought to 1800°C over a period of 1/2 hour. The Xe^{133} released was continuously swept from the furnace by a helium purge and collected in a liquid nitrogen-cooled charcoal trap which was monitored continuously. I^{131} and Te^{132} were collected on a cold finger which extended down the length of the furnace heater tube to within one inch of the sample. The cold finger was sampled periodically in order to obtain several data points for the I^{131} and Te^{132} release. Ba^{140} was caught on a graphite liner upon which the sample rested during the annealing experiment and the amount was determined upon the completion of the experiment. The tungsten sleeve picked up very little (~1.5%) of the total Ba^{140} released.

The release data are shown in Fig. 2 and Table 1. From the slopes (for Xe^{133}, the slope of the line between 40.5 and 46.4 hours was used) in the linear regions of these plots after the initial rapid releases had occurred, the rates of release of these fission products were calculated and are shown in Table 2.

As seen from Fig. 2, the Xe^{133} release data from this sample reveal a sensitivity to thermal cycling. Small bursts of Xe^{133} release occurred each time when the furnace was cooled for the collection of the condensate on the cold finger; the first burst was missed when trapping was temporarily interrupted. It is possible that micro-cracks might have occurred in the sample upon cooling (1800°C to 500°C in 10 mins. and 500°C to room temperature in 20 mins.) which facilitated the release.

Fig. 2

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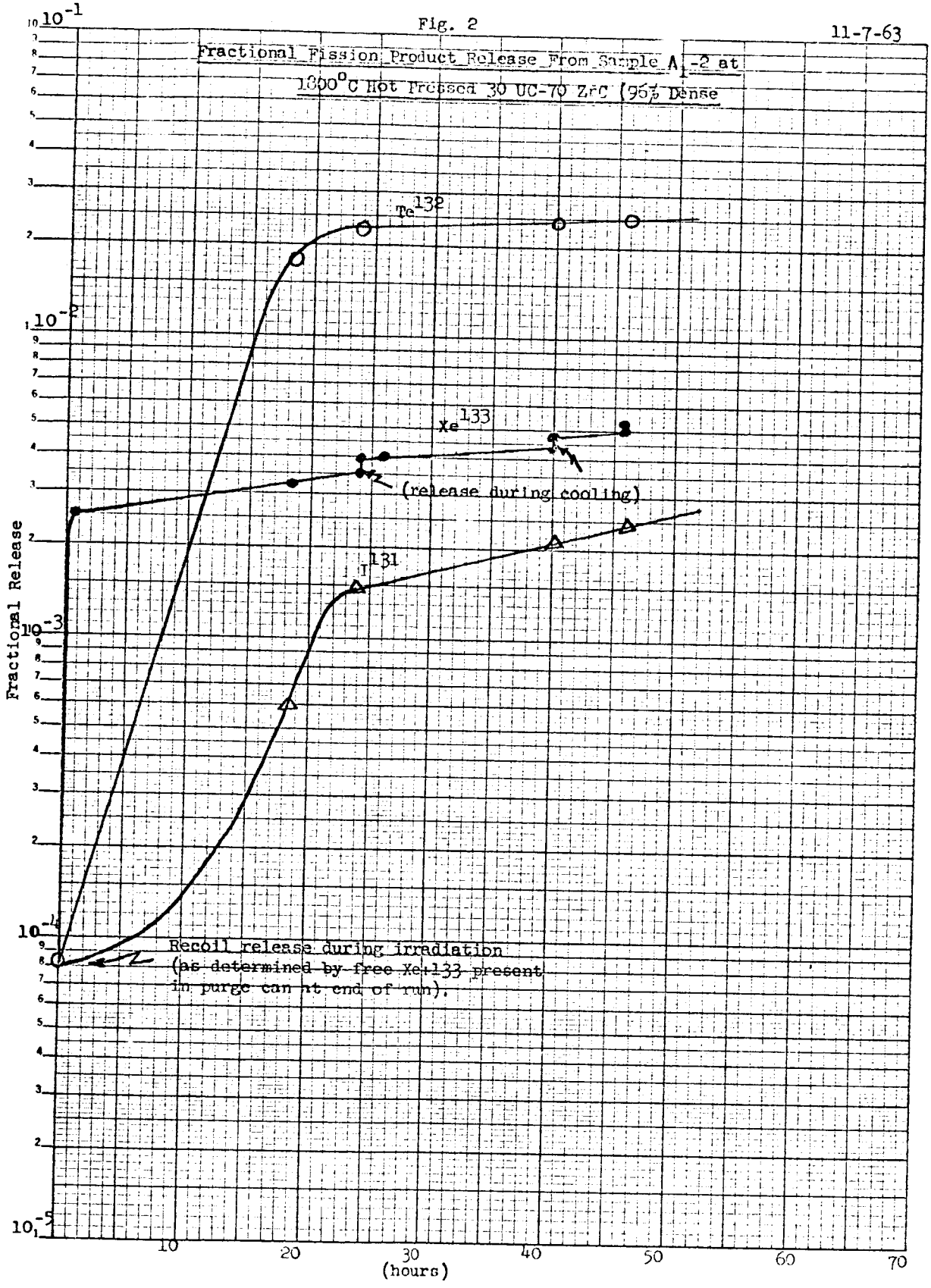

Fractional Fission Product Release From Sample A1-2 at
1800°C Hot Pressed 30 UC-70 ZrC (95% Dense
Te132
Xe133
(release during cooling)
I131
Recoil release during irradiation
(as determined by free Xe+133 present
in purge can at end of run).
Fractional Release
(hours)

For this experiment, only one point for Ba^{140} release was obtained. In the future, the rate of release will be measured by changing the graphite sleeve each time the cold finger is changed. At least one other nuclide has been observed on the graphite sleeve. Attempts are being made to identify it as a fission product. At the same time, activation analysis is being performed on the Zr used in the sample to determine if the unknown isotope is an activated impurity.

Radiochemical analyses are now being performed on sample A_1-2 to determine the amounts of Cs^{137} and $Ce^{141, 144}$ retained.

Sample A_1-3 which is cut from the same carbide cylinder as A_1-2 will be studied similarly at 1900°C.

2.3 Fission Product Diffusion through W-clad.

The fabrication of one of the cells is 90% completed. The vacuum system is being assembled. It is decided to test this cell first before the second cell is built. The pulse-height analyzer has been ordered. The first sample will be a vapor-deposited tungsten clad low density 30 UC - 70 ZrC cut from the same carbide cylinder as sample A_2-1 (see Sec. 2.1). The use of a low density fuel sample will insure that the release of fission product from the fuel is not the rate determining step of the over-all process so that some preliminary ideas may be gained on the rates of diffusion of various fission products through the clad. Assembly and test of the cell and the preparation of the first sample are expected in November.

2.4 Fuel-Clad Gross Diffusion Studies

Materials ordered for this work are being received. Fabrication of the fuel specimens are about 50% completed. The Ta heater in the

furnace used previously for diffusion studies is being rebuilt. Bids have been received for the second diffusion furnace. These are being evaluated and a purchase order will be issued shortly. It is expected that experimental work will commence in November.

2.5 Fuel-Clad Diffusion-Emission Studies

Studies have been made on a Re clad UC sample E_1. The sample was prepared by bonding a 20 mil thick Re sheet to a cast W cup containing a cold-pressed and sintered UC wafer (20 mil thick, 4.63%C). The bonding was carried out in a vacuum hot-press at 1900°C for a period of 1 1/2 hours. To prevent the graphite plungers from reacting with the Re and the W, a 5 mil thick W sheet was used as a spacer at the cast W side and a 20 mil W-26Re sheet and a 5 mil W sheet were used as spacers at the Re side, with the W-26Re sheet facing the Re. After bonding, the sample was pressurized with helium and checked for the soundness of the bond by immersion in acetone. The spacer sheets were then machined off by electrical discharge machining (EDM). To insure a clean Re surface, the top 7 mils of the Re layer was also removed by EDM so that the final thickness of the Re clad was 13 mils.

The sample was heated in the diffusion-emission cell for 64 hours at 1923°K, 170 hours at 2063°K, 50 hours at 1663°K and finally another 16 hours at 2063°K. The Schottky plots obtained after the sample was 1 hour, 24 hours and 186 hours at 2063°K are shown in Fig. 3. It can be seen that after the sample was heated at 2063°K for only 1 hour (after 64 hours at 1923°K), the saturation emission at zero field was 30 m.a/cm^2 as compared to a value of 0.4 m.a./cm^2 for Re at the same temperature. After 24 hours at 2063°K, the emission could not be saturated because the

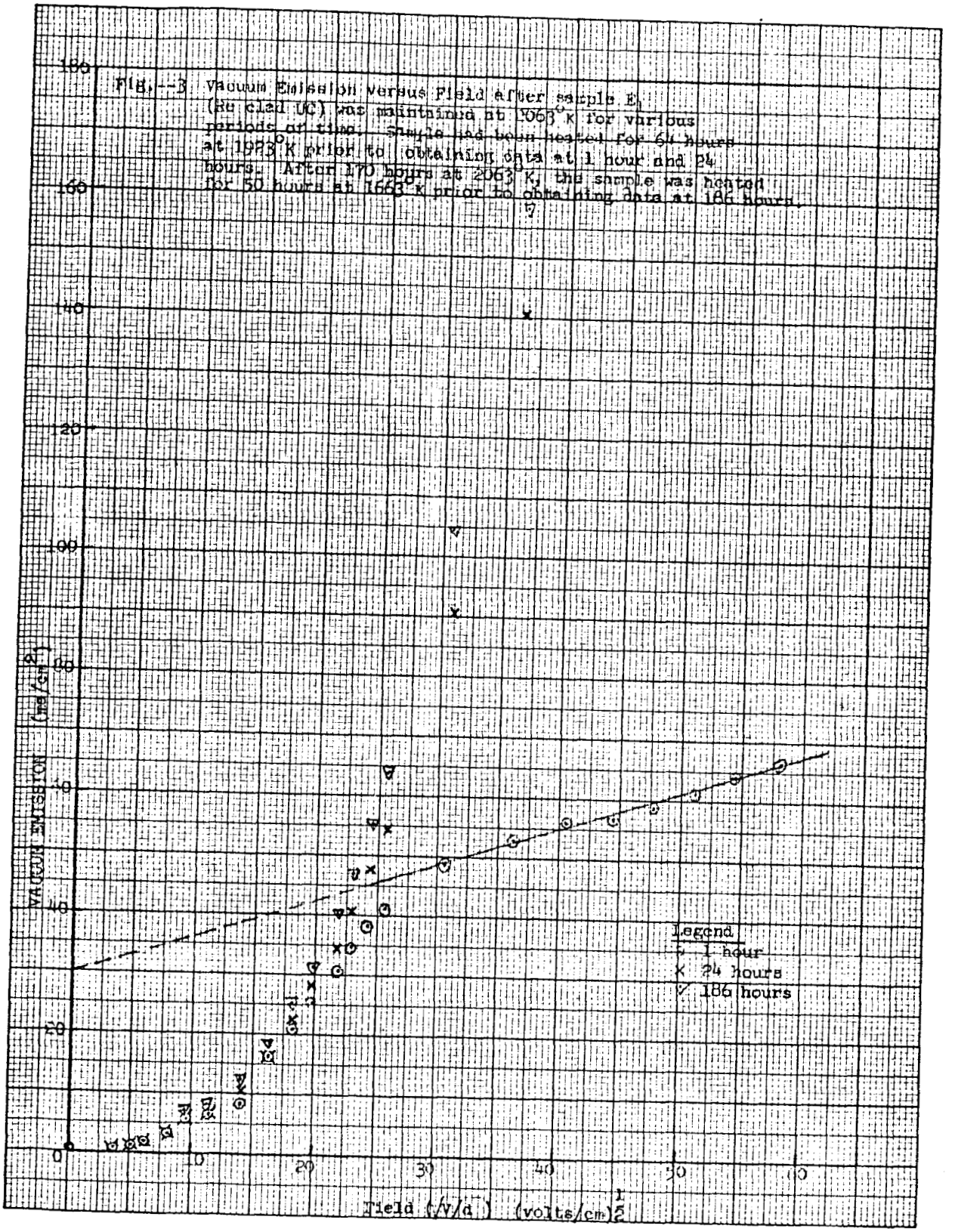


Fig. 3 Vacuum Emission versus Field after sample E (Re clad UC) was maintained at 1063°K for various periods of time. Sample had been heated for 64 hours at 1973°K prior to obtaining data at 1 hour and 24 hours. After 170 hours at 2063°K, the sample was heated for 50 hours at 1663°K prior to obtaining data at 186 hours.

Mo collector and the Mo guard ring which were both floated, became excessively heated due to the large current emitted from the surface of the sample. Saturation could be achieved, however, when the sample was cooled to 1663°K (after 170 hours at 2063°K). Fig. 4 shows the variation of the vacuum saturation emission with time at 1663°K. The emission increased with time, indicating a continuous adjustment of the surface composition by diffusion. Although a steady state was not reached after 50 hours at 1663°K, it is apparent that the saturation emission of the surface at the end of 50 hours (14 m.a./cm^2) is many orders of magnitude higher than that of pure Re (5×10^{-4} m.a./cm^2) at the same temperature.

Sample E_1 is now being examined metallographically for the structures of the UC, the Re clad and the Re-UC interface.

The results obtained seem to indicate that for sample E_1 an interaction had occurred between Re and UC, which caused a large increase of its vacuum emission. Some of the interaction might have occurred during the bonding of the Re to the cast W cup containing the UC wafer at 1900°C in the hot press. Unfortunately no good bond could be formed by hot pressing at lower temperatures within a few hours. To avoid this difficulty, another Re clad UC sample will be made for similar studies during the coming month by sealing the interface between the Re and the W cup containing the UC wafer by vapor deposited W. In addition to the Re clad UC sample, two other diffusion-emission samples will be prepared for studies at 2073°K. These are W-26Re clad UC and vapor-deposited W clad UC. It is intended to use stoichiometric or slightly hyperstoichiometric UC in all these samples.

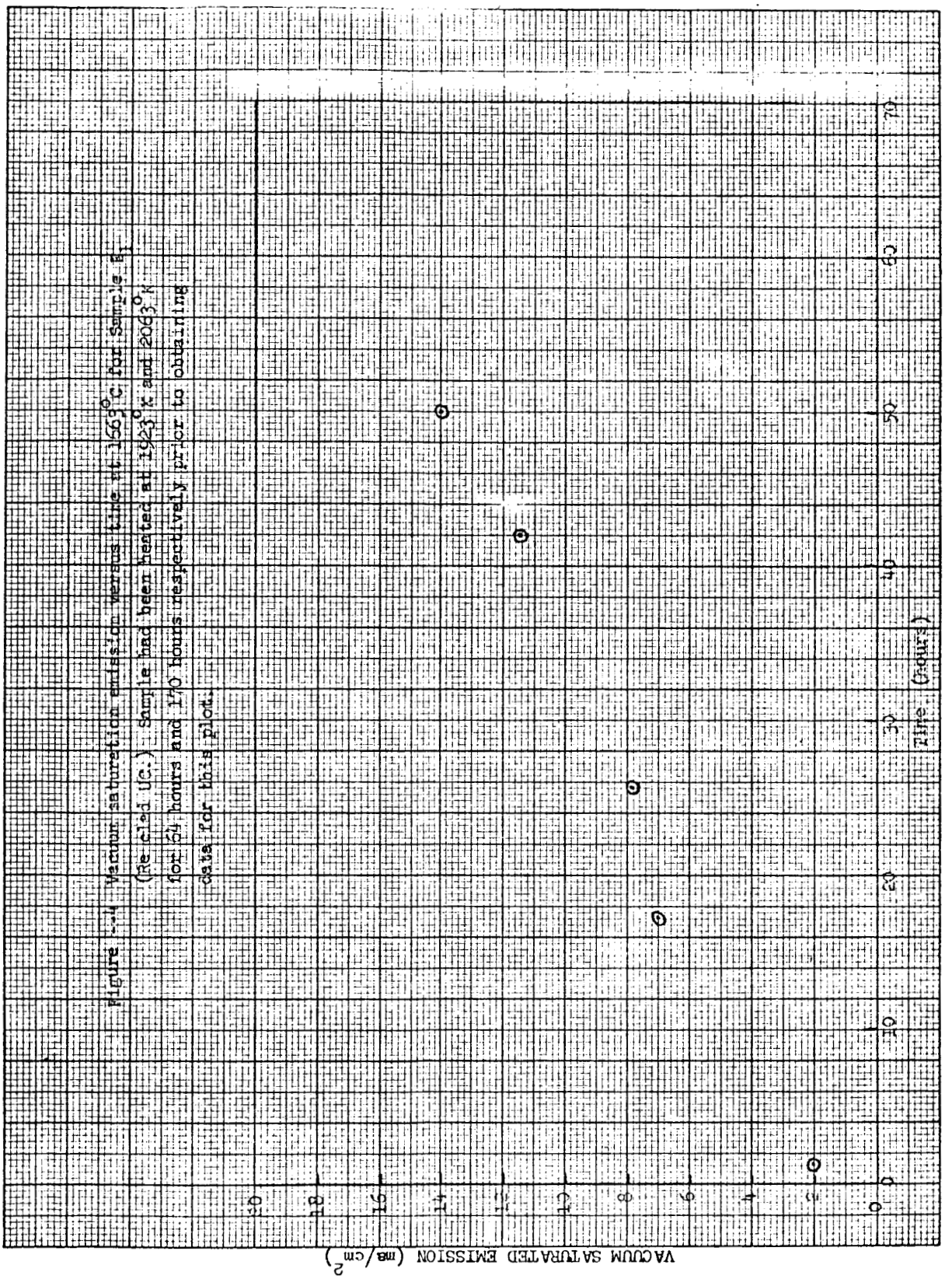


Figure 4 Vacuum saturation emission versus time at 1569°C for Sample #1 (Re clad Uc.) Sample had been heated at 1963°K and 2063°K for 24 hours and 140 hours respectively prior to obtaining data for this plot.

2.6 Refractory Metal Interdiffusion.

About 50% of the refractory metals ordered have been received. Samples of these metals are being machined to the dimensions required in the machine shop for the diffusion studies.

2.7 Refractory Metals Diffusion-emission Studies.

The fabrication of the diffusion-emission cell has been completed. The chemicals needed for the electrodeposition of Ir have been ordered. The vapor deposition of Re over W is being looked into.

2.8 Mechanical Properties of UC-ZrC.

The Mo support pedestal is being redesigned. It is expected that fabrication of the modified pedestal will commence in November.

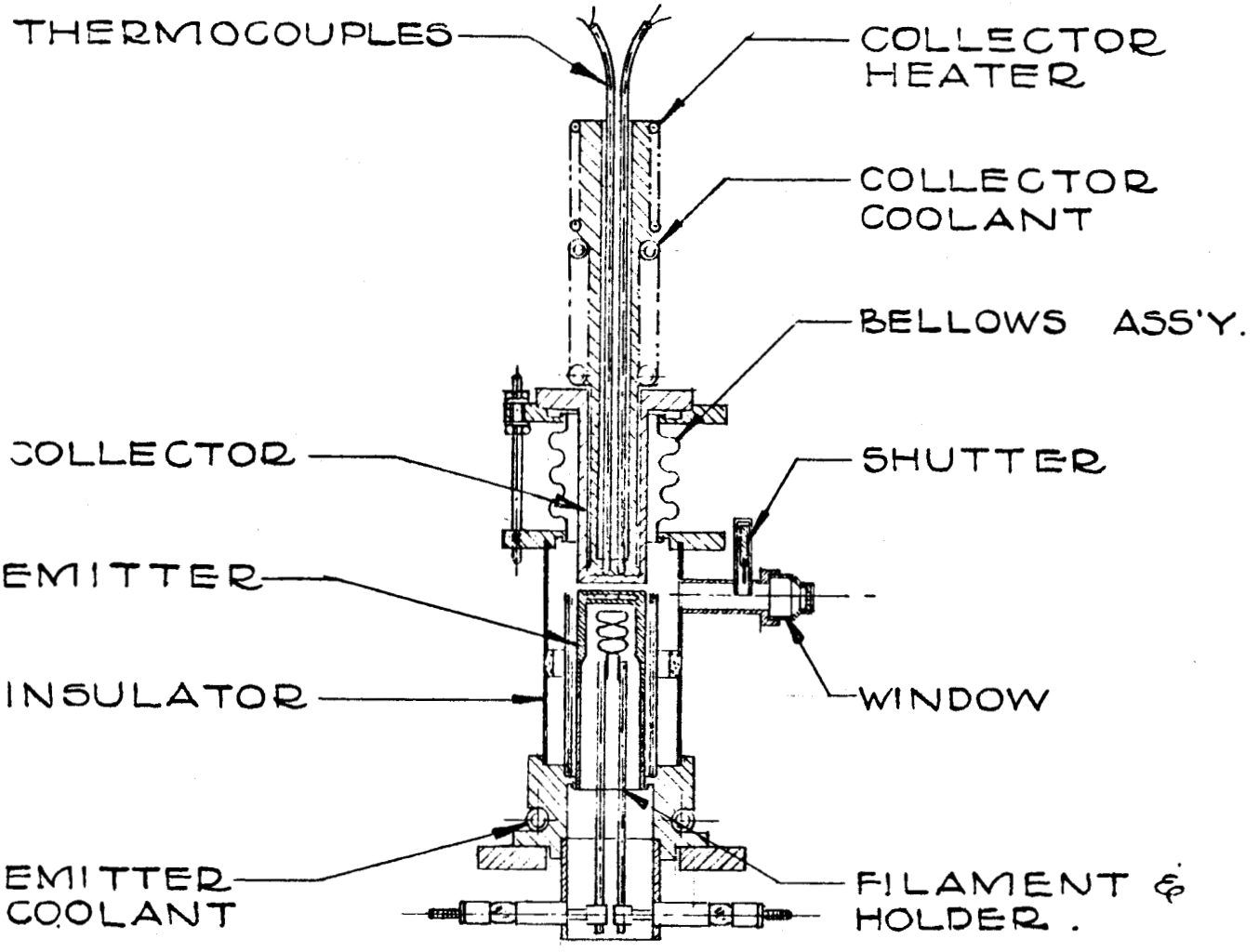
2.9 Thermionic Emission Microscopy of W-(uranium-containing carbide) Cermets.

A cermet sample containing 10 wt-% W and 90 wt-% 30 UC-70 ZrC powder has been prepared. The sample is now being outgassed at 1800°C in the emission microscope. Examination of its emission pattern will be started after the outgassing is completed.

3. Life-Testing of Cesium Thermionic Cells.

3.1 Cell Design

The design of the parallel geometry converter for life testing of clad and unclad emitter materials was completed. The schematic of Fig. 5 shows the design. The longest fabrication development phase will be the emitter. However, there is considerable lead time required for some materials and fabrication of the insulator-seal bellows assembly. The design of the emitter assembly is shown in Fig. 6. The primary objective of the redesign is to attain an operating lifetime of 10,000 hr.



MARK I

Figure 5

To accomplish this several changes were made from the previous design of the Materials Life Performance cell. These are briefly:

(1) A reduced number of joints by eliminating the guard ring.

(2) Better thermal expansion match of materials for brazed and welded joints.

(3) Operation in a vacuum produced by a (non-oil) Vac-Ion pumping system.

(4) A thick tungsten housing for the bombardment filament.

The plan for operation of the cell in vacuum required some cooling system design. The coolant for the collector and emitter stem support is air in stainless steel coils. It is planned to cool the Kovar-Al_2O_3 insulator seal by radiation from Kovar fins brazed to the insulator. These changes all required heat-transfer calculations.

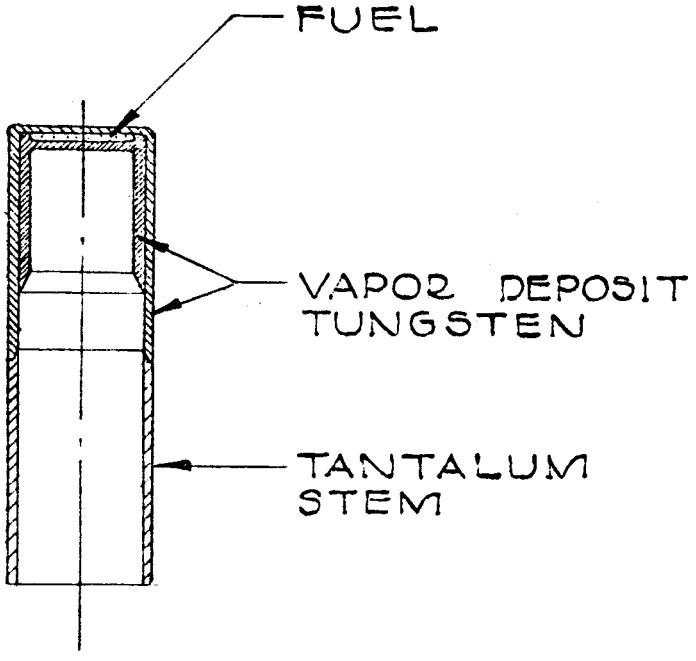
The elimination of a guard ring accomplishes the following improvements.

(1) One insulator and its ceramic-metal seals are eliminated along with two braze joints.

(2) The collector assembly is shortened, thus reducing the thermal expansion.

(3) Facilitation of fabrication by elimination of a difficult assembly.

The emitter structure was analyzed thoroughly by the RAT (Radial Axial Thermal) computer code to determine the best design. This analysis showed that the design given in Fig. 6 is optimum. Also, a helical geometry electrical bombardment filament is the best method of heating for proper temperature distribution.



EMITTER MK I

Figure 6

3.2 Cell Fabrication.

A considerable effort has been expended in working with the designers to obtain a fabricable cell. Work has also commenced on "perting" the cell schedule to determine the critical path lengths.

Experimental work has commenced in the development of a phototype emitter.

Five vapor-deposited tungsten blanks were procured -- two suitable for clad-emitter structures, and three suitable for bare-carbide emitters. Six specimens of 30 UC-70 ZrC were fabricated for use in clad systems and were seal-coated with vapor-deposited tungsten prior to final cladding. One emitter has been machined to accept the carbide specimen. This assembly has been submitted to San Fernando Laboratories for final cladding. Preparation of the other clad emitter will be held up until the first is completed in order to incorporate any changes in design or procedure which are found to be required.

3.3 Cell Testing.

Eight new test stations were designed for high vacuum testing 10^{-8} torr) of the NASA life test converters. The vacuum system includes a 100 liter/sec Vac-ion pump and a 12" bell jar. Nine ports will be provided for the admission of 12 thermocouples, 4 cooling lines, 4 heater circuits, and 2 high current conductors. The system will be roughed with Vac-Sorb pumps to eliminate any possibility of contamination by fore-pump oils.

The emitters will be powered by regulated electron bombardment heaters. This will assure a constant emitter temperature during unattended operation. The emitter temperature will be monitored with two (replaceable)

sheathed W/W-26 Re thermocouples. One will be used for emitter temperature recording; the other used in conjunction with a limiting device that will disconnect the bombardment voltage when a preset maximum temperature has been exceeded.

The collector and cesium reservoir temperature will each be measured by two chromel-alumel thermocouples, one for recording and the other for controlling. Collector temperature regulation will be accomplished through a duration-type controller that actuates a cooling air solenoid valve. The cesium reservoir temperature will be adjusted by a time proportioned temperature controller with a 1/2% accuracy.

A 200 channel electronic data logger will be used to measure the cell converter temperatures as well as input and output power. This data will be logged for a permanent record on a 1" paper tape with an eight level I.B.M. code at a rate of 4 channels/sec. The data will then be processed through a reader and a computer with the resulting output printed in a tabulated form or plotted. The logger can be slowly stepped through each channel enabling the operator to observe and manually record any desired data. In addition, provision will be made to observe all parameters on conventional volt, amp, and millivolt meters.

4. Irradiation Studies.

On the basis of information generated under Project 306.35 which is an extension of Contract NAS 3 2532, preliminary discussions were held at Lewis Research Center with Messrs. D. Hegberg, H. Schwartz, J. Creagh and F. Glaski on October 10, 1963 on the feasibility of Plum Brook Reactor for the irradiation studies under the present contract.

A copy of a preliminary Request for Irradiation was deposited with Mr. Hegberg for his comments which were subsequently forwarded to General

Atomic through Mr. Creagh. Since the termination of Project 306.35 on October 13, 1963, efforts for gathering the information needed for modifying the preliminary draft on the basis of Mr. Hegberg's comments have been continued under the present contract. The work carried out in October is summarized as follows.

4.1 Design.

The preliminary design of the capsule is essentially completed and drawings are being finalized. A detailed description of the design is being prepared for the Request for Irradiation for presentation to the Plum Brook Policy Committee. A summary of the design is included in the final report of Project 306.35.

The system selected for the cooling mechanism is the forced convection flow using the available pressure head of 155 psig from reactor primary water cooling system. The cooling water is then returned to the reactor primary water system at 115 to 120 psig by a small centrifugal pump. It is planned to pressurize the water in the V-tube to allow low flow rates of the order of 3 gpm per capsule. The details of the equipment layout and safety instrumentation are being worked on.

A handling scheme for removing irradiated capsules is also being designed. The two methods considered were: (1) discharging into a lead shielded cask, and (2) discharge to the reactor fuel discharge chute. The first method involves a very heavy lead cask of the order of 15,000 pounds. This would require a supporting structure above the reactor vessel since the V-tube flange could not support the weight. This method would be extremely costly. The second method would involve putting a door in the side of the V-tube. This door would be assembled by lowering the reactor

water and then assembling the door from a lowered platform. For discharge of the capsule, the door would be opened from this platform. The irradiated capsule would then be handled by remote grappling mechanisms for cutoff and transfer for the fuel discharge chute. This door would be used to guide a capsule into the positioning mechanism to replace the discharged capsule.

Design calculations are in progress to estimate the effect of an opening in the V-tube, relative to the problem of sealing the door. The pressure differential across the V-tube is of the order 25 to 30 psi.

4.2 Nuclear Calculation.

Two-dimensional diffusion calculations of the Plum Brook core and reflectors were used to determine the unperturbed neutron flux in the V-1 tube region. Transport calculations were then utilized to evaluate the flux depression into the fuel samples of the irradiation capsule. This information together with detailed thermal calculations was employed to determine the temperatures attainable and the variation in temperature as a function of U-235 concentration in the sample and capsule position. The utility of a RAFT facility (i.e., controlled movement of the capsule) in maintaining prescribed temperatures throughout an experiment was determined. With the amount of control available within the confines of the 8-in. V-1 tube, it was shown that adequate temperature adjustment is available within fairly small limits ($\pm$ 30%).

The results of the nuclear analysis of the Plum Brook Reactor, coupled with cell calculations of the capsule, calculations of the power generation in the materials irradiation capsule, and calculations of the fuel surface temperatures in the capsule, indicate that the test requirements can be met through the proposed irradiation program in the V-1

(or V-2) facilities of the Plum Brook Reactor. The requirements necessary for a successful experiment were evaluated and confirmed to be present in the V-1 region. Predicted fuel body surface temperatures are shown in Tables 3 and 4 for an irradiation capsule of the design similar to that shown in Fig. 11 of GA-3866 (NASA Quarterly Progress Report for period ending November 30, 1962). A detailed description of the calculations and results has been compiled and will be included in the Request for Irradiation.

4.3 Testing.

A final draft of Request for Irradiation in Plum Brook Reactor is being prepared. It is expected that the request will be forwarded to Lewis Research Center by November 15, 1963.

Table 1

Fractional Fission Product Release from Sample A_1-2 at 1800°C, Hot-Pressed 30 UC-70 ZrC 96% Dense

Hrs. at 1800°C	Xe^{133}	Te^{132}	I^{131}	Ba^{140}
0 (recoil)	7.9×10^{-5}	-	-	-
18.5	3.2×10^{-3}	1.8×10^{-2}	5.9×10^{-4}	-
24	3.4×10^{-3}	-	-	-
(after cooling)	3.8×10^{-3}	2.2×10^{-2}	1.4×10^{-3}	-
40.5	4.2×10^{-3}	-	-	-
(after cooling)	4.6×10^{-3}	2.4×10^{-2}	2.0×10^{-3}	-
46.5	4.9×10^{-3}	-	-	-
(after cooling)	5.2×10^{-3}	2.5×10^{-2}	2.3×10^{-3}	2.0×10^{-3}

Table 2

Rate of Release of Fission Products from Sample A_1-2

Isotope	Fractional Release per hour
Te^{132}	1.3×10^{-4}
Xe^{133}	5.0×10^{-5}
I^{131}	4.0×10^{-5}

Table 3

Fuel Temperature (°C) as a Function of

Position in the V-1 Tube Region

Distance Out from Aluminum Wall, cm

	5.0	8.0	11.0	14.0	17.0	20.0	23.0
61.0	1560	1330	1150	1030			
58.0	1700	1430	1220	1070			
55.0	1820	1530	1290	1120	1000		
52.0	1920	1620	1370	1060	1040		
49.0	2020	1710	1440	1220	1070		
46.0	2120	1800	1500	1270	1100		
43.0	2190	1880	1570	1320	1120	1000	
40.0	2280	1950	1640	1370	1160	1010	
36.6	2370	2030	1710	1430	1200	1050	
33.6	> 2400	2100	1770	1470	1230	1070	
30.6	> 2400	2170	1820	1520	1260	1080	
28.0	> 2400	2210	1870	1550	1290	1100	
25.0	> 2400	2260	1910	1590	1310	1120	
21.9	> 2400	2300	1940	1610	1340	1130	980
18.9	> 2400	2330	1960	1625	1350	1140	985
15.9	> 2400	2335	1970	1630	1350	1140	985
12.9	> 2400	2330	1960	1620	1340	1130	980
8.9	> 2400	2290	1930	1600	1320	1120	
6.9	> 2400	2240	1880	1550	1290	1100	
3.9	> 2400	2170	1810	1500	1250	1080	
0	> 2400	2020	1690	1380	1180	1020	

Rods In (15.4") P = 45 Mw

UC (30) - ZrC (70), Enr. = 93%

Table 4

Fuel Temperature (^{o}C) as a Function of
Position in the V-1 Tube Region

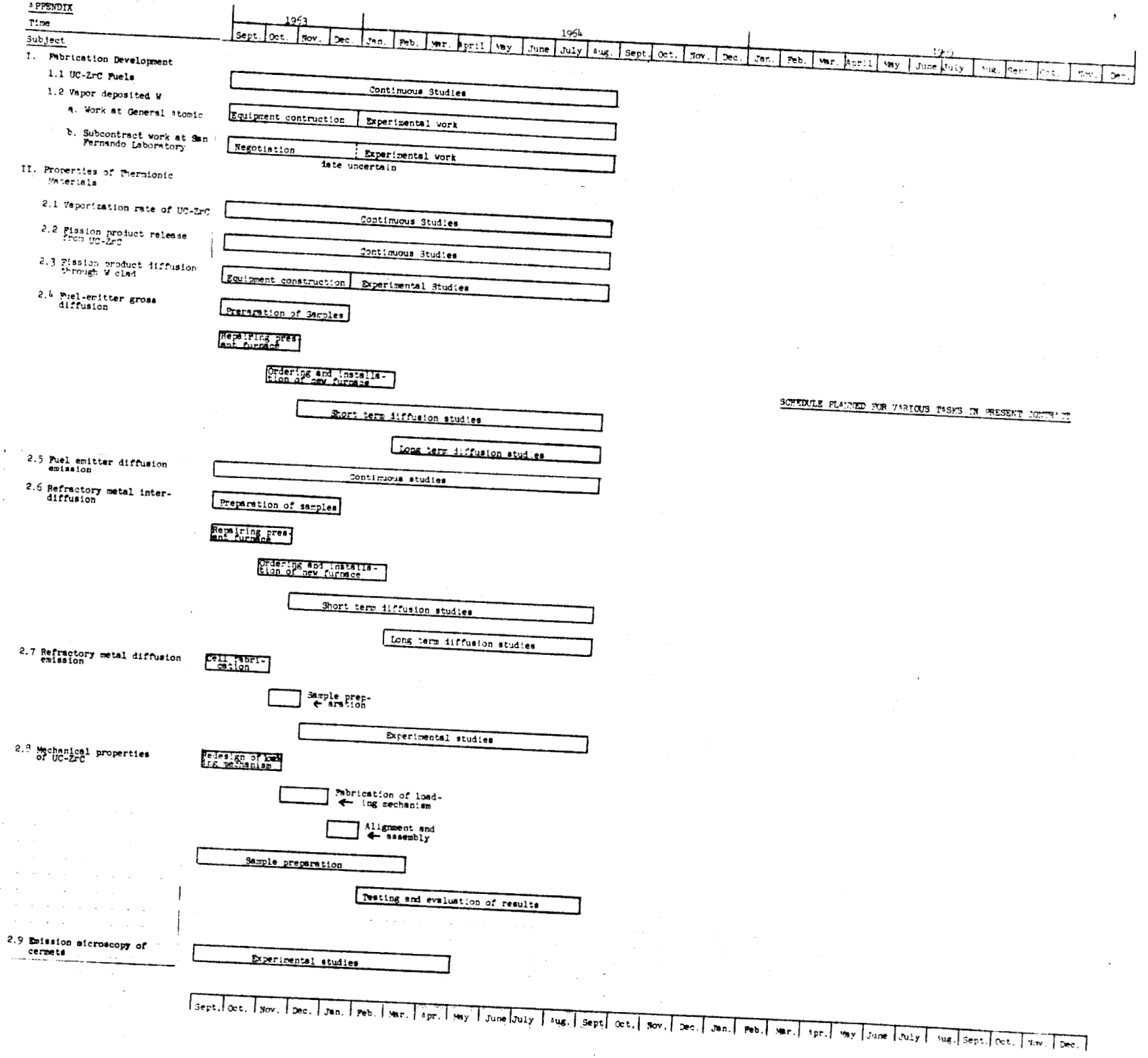
	Distance Out from Aluminum Wall, cm						
	5.0	8.0	11.0	14.0	17.0	20.0	23.0
61.0	2090	1760	1460	1230	1070		
58.0	2240	1890	1570	1300	1120	980	
55.0	2350	2000	1660	1380	1160	1000	
52.0	>2400	2090	1750	1440	1200	1050	
49.0	>2400	2160	1800	1490	1250	1070	
46.0	>2400	2220	1860	1540	1290	1090	
43.0	>2400	2260	1910	1580	1300	1100	
40.0	>2400	2290	1940	1610	1330	1120	
36.6	>2400	2330	1960	1630	1350	1130	980
33.6	>2400	2340	1980	1640	1350	1140	985
30.6	>2400	2340	1980	1640	1350	1140	985
28.0	>2400	2340	1980	1640	1350	1140	985
25.0	>2400	2310	1970	1630	1350	1140	980
21.9	>2400	2300	1950	1620	1340	1120	
18.9	>2400	2280	1920	1590	1310	1110	
15.9	>2400	2240	1880	1550	1290	1100	
12.9	>2400	2180	1830	1520	1260	1080	
8.9	>2400	2320	1770	1470	1230	1060	
6.9	2380	2240	1700	1410	1180	1040	
3.9	2290	1950	1620	1320	1140	1000	
0	2120	1780	1480	1250	1080		

Rods Out P = 60 Mw

UC (30) - ZrC (70), Enr. = 93%

APPENDIX

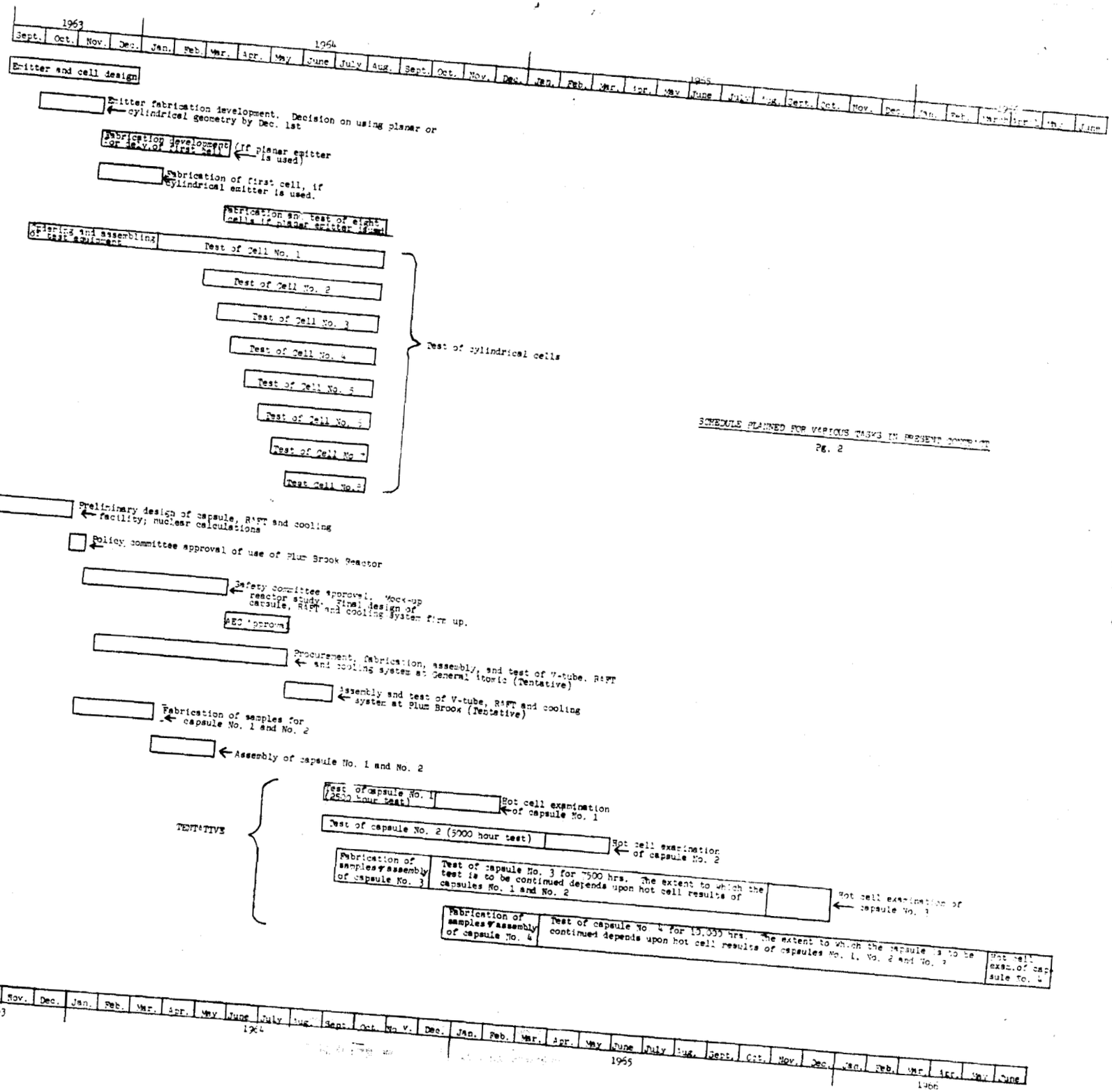
SCHEDULE PLANNED FOR VARIOUS TASKS IN PRESENT CONTRACT



III. Life Testing of Cesium Cells

IV. Irradiation Studies

Only the schedule for the high temperature clad capsule is shown because only one V-tube is available. The capsule consists of two identical parts, capsule No. 1 and capsule No. 2, which can be discharged separately. The schedule is set up on the basis of the following assumptions: (a) The reactor operates on 50% duty cycle, (b) the 5,000 hr. test schedule merges with the 10,000 hr. test schedule, and (c) capsules are discharged and reloaded at 2500 hr. intervals so that test results can quickly be fed into the material developmental efforts without an unduly long waiting period. Similar schedule can be set up for the low temperature capsule when another V-tube is available. The schedule should be such that maximum benefit could be drawn from the test results of one type of capsule to guide the test program of the other.



SCHEDULE PLANNED FOR VARIOUS TASKS IN PRESENT CONTRACT